DCIEM 94-11

ACTIVE NOISE REDUCTION SYSTEMS: THEIR INTERACTION WITH VERY LOW FREQUENCY ACOUSTICAL ENERGY

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ABSTRACT

The technique of Active Noise Reduction (ANR) uses interfering sound waves to reduce noise exposure. ANR systems have become commonplace in transportation equipment as a method for creating a favourable environment to perform auditory tasks. Recent field experience has shown that high-amplitude low-frequency sound encountered in helicopters and tracked vehicles causes some ANR systems to overload or saturate. This is perceived as the presence of extraneous noise at the ear. A technique is described wherein low-frequency ANR performance may be assessed by measuring the threshold of overload. The results of this procedure indicated large differences in the saturation thresholds among systems tested. A strong dependence upon the integrity of the ear seal was also noted. Those systems offering active attenuation into the infrasound region tended to saturate most easily, but did create the best listening condition for the user when operated below the saturation threshold.

INTRODUCTION

Active Noise Reduction, or ANR, is a technique for reducing noise at the ears of an observer through the action of interfering sound waves. Noise in the vicinity of the ear is sensed by a miniature microphone built into the ear cup of a headset or helmet containing the ANR system. The microphone signal is processed and reintroduced by a miniature loudspeaker into the ear cup cavity out of phase with the original sound, thus effecting a net cancellation of noise at the ear. The use of ANR systems is now commonplace in transportation equipment. ANR provides a cost-effective way to reduce noise exposure and to enable the discrimination of speech or the detection of other signals at reduced levels of presentation. ANR is thought to suppress the noise causing upward spread of auditory masking which would otherwise interfere with the performance of these tasks. DCIEM has been evaluating a number of commercial ANR systems for use in helicopters and tracked vehicles. The overall attenuation properties of these systems have been reported by Crabtree and Rylands, 1992.

Recent field experience has shown that system exposure to very high-amplitude low-frequency audible and sub-audible sound can lead to saturation or overload of the ANR electronics. Saturation causes the system to generate extraneous noise at the ear described variously as a clicking, popping or oil-canning sound. A technique was developed wherein the low-frequency behaviour of ANR equipment could be assessed by measuring the threshold or onset of overload as a function of frequency.

METHOD

The saturation thresholds of the candidate ANR systems, or the maximum at-ear sound levels for which non-distorted cancellation waveforms could be generated, were measured over a frequency range of 10 - 40 Hz. To accomplish this, a KEMAR acoustical manikin headform with Zwislocki coupler artificial ears (Burkhard and Sachs, 1975) was modified by removing the couplers and mounting plates from the ear cavities. This provided 27 mm circular openings from the circumaural areas into the hollow headform. Calibrated 12.7 mm microphones were suspended in these openings such that their diaphragms were flush with the outer surface of the headform, thus allowing air to pass freely through the openings. The hollow neck of the headform was attached to the interior of a loudspeaker enclosure containing a 200 mm low-frequency driver.

When an ANR helmet or headset was placed over the ear openings and the loudspeaker excited by a low-frequency pure tone, it was possible to excite the ear cavities to sound pressures exceeding 140 dB. The ANR system could not distinguish between this type of excitation and that which normally permeates the ear shells, thus ANR attempted to establish an opposing noise field. Since the measurement microphones were placed in proximity to the cancellation transducers, they were sensitive to the onset of distortion or overload. The resulting extraneous noise became clearly audible over headphones used to monitor the microphones as the excitation level passed through the threshold. Sound pressure levels registered by the microphones at the threshold were then plotted as a function of frequency.

Although the preceeding experiment describes ANR behaviour within the ear cup at very low frequencies, it does not quantify the effect of the ear cushion or the seal against the side of the head. This information is required to define the magnitude of an external sound field which will cause the threshold to be exceeded. To study this question, another simulator in which the entire helmet/ANR system could be subjected to low-frequency high-pressure sound was used. This simulator was a large sealed loudspeaker enclosure with a 300 mm driver. Access to the interior was accomplished by removing the driver then inserting the helmet through the opening. Inside the enclosure, measurements were accomplished using a heavy flat-plate coupler with a microphone at its centre.

Insertion-loss measurements were carried out with the coupler in free air and pressed against one of the helmet's ear seals as the driver was excited by low-frequency pink noise. Attenuation data were given as the difference between the spectra. With this apparatus, the effect of controlled air leakage into the ear cavity through a tube 1.6 mm inside diameter x 20 mm length was also determined. The tube was embedded in a wedge of plasticine to prevent air movement around its periphery. The opening created by the insertion of the metal side arm of eye glasses was also assessed. Details of the test fixtures used in these studies have been reported by Welker, 1993.

RESULTS AND DISCUSSION

The saturation threshold levels of several ANR systems are given in Figure 1. The traces describe the highest levels of low-frequency at-ear pure tone sound levels that the systems could accommodate without generating extraneous noise. The differences between these curves are thought to be attributable to two interrelated factors. First, those systems providing significant cancellation within this frequency range simply worked harder in the presence of infrasound excitation, and second, hardware constraints such as the excursion limits of the cancellation transducers or the power available to drive them ultimately determined the saturation threshold. The devices having extended low-frequency

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A typical noise spectrum resulting from overload is shown in Figure 2, where the excitation was a16-Hz pure tone presented 5 dB above the saturation threshold. For reference, the comparable spectrum with ANR in defeated or passive mode is also shown. The difference between the traces represents the extraneous noise which was most pronounced at frequencies between 100 and 1000 Hz. This raises the possibility of interference with the lower portions of the speech band.

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As an example of practical implications, the largest acoustical input to the cabin of a Sea King helicopter occurs at the main rotor blade-pass frequency, about 17 Hz, as shown in Figure 4. An air leak as small as that described above would force the ANR electronics to accommodate ambient (rather than attenuated) levels of infrasound, as well as higher-than-ambient levels of the 2nd - 5th order harmonics of rotor blade pass noise. Experience has shown that a perfect seal against the head is rarely achieved in a field situation. Thus, for a given ANR system to perform satisfactorily in this helicopter, it needs to be capable of generating very high levels of infrasound.

CONCLUSION

Environments in which ANR has the potential to provide the greatest benefits to the user often contain low-frequency noise of sufficient amplitude to cause ANR equipment to malfunction. ANR performance at very low frequencies appears to depend upon the capability to generate cancellation waveforms within this frequency range, upon hardware constraints such as transducer excursion limits and upon the integrity of the seal against the head. The data presented in this paper emphasize the importance of understanding the behaviour of ANR devices at extremely low frequencies and the relationship to the envionment in which it will be used.

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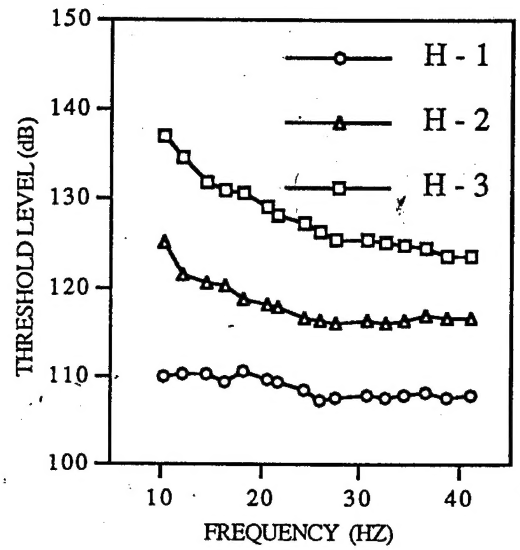

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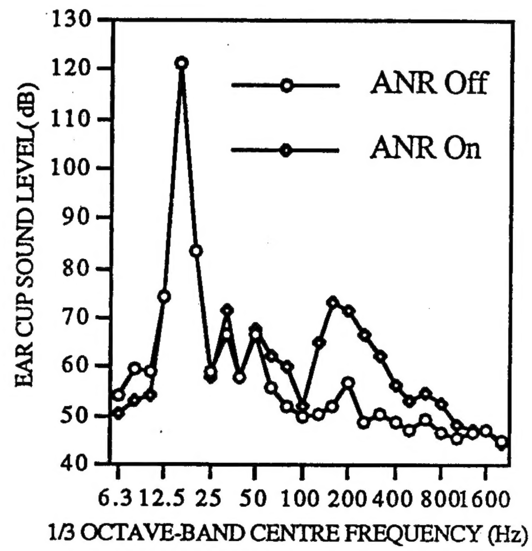

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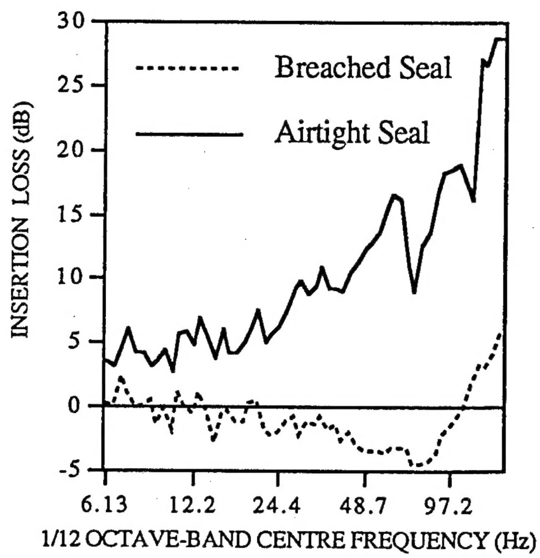

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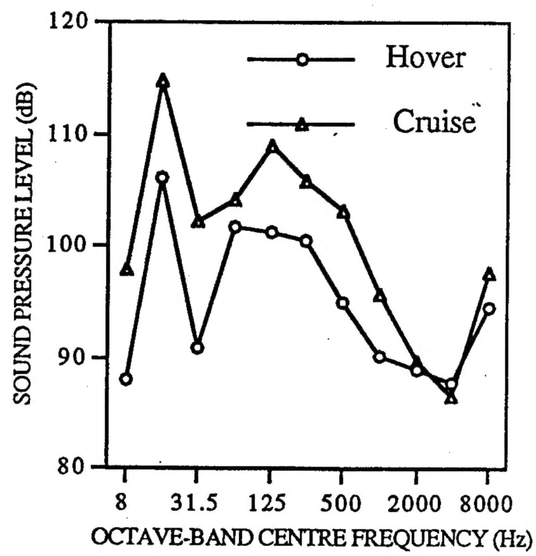

Figure 4. Ambient sound levels on the flight deck of the Sea King helicopter

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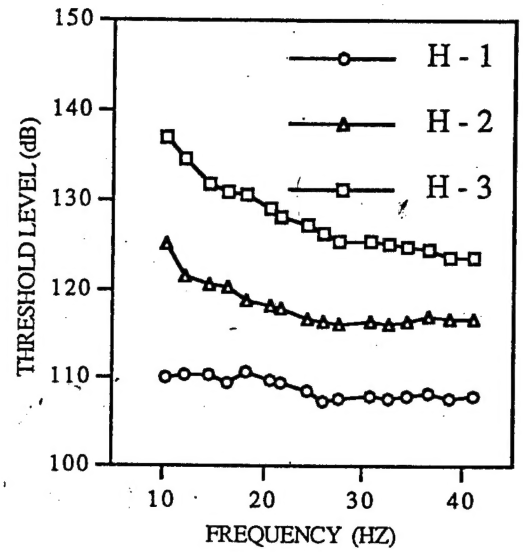

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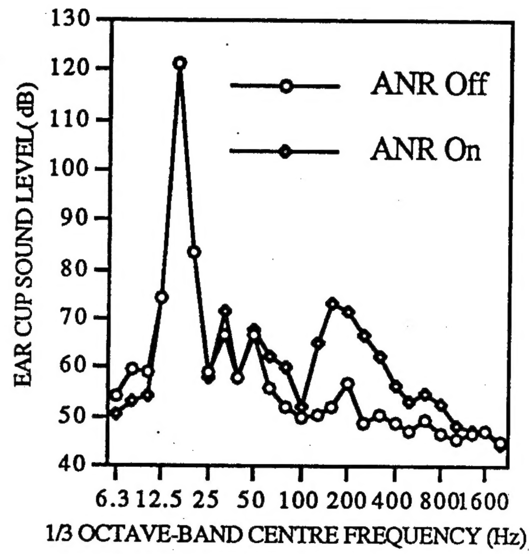

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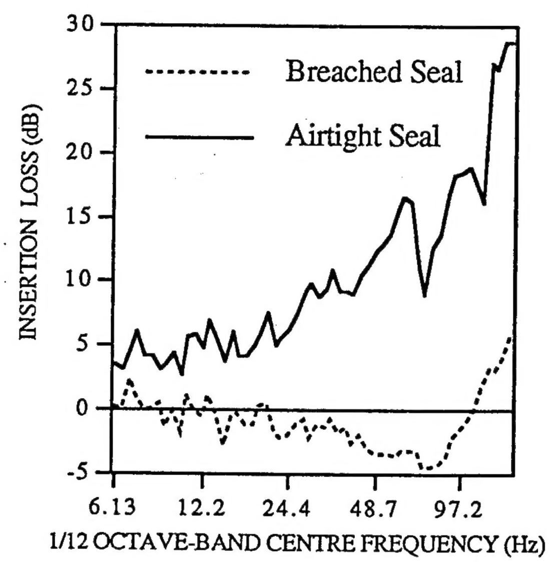

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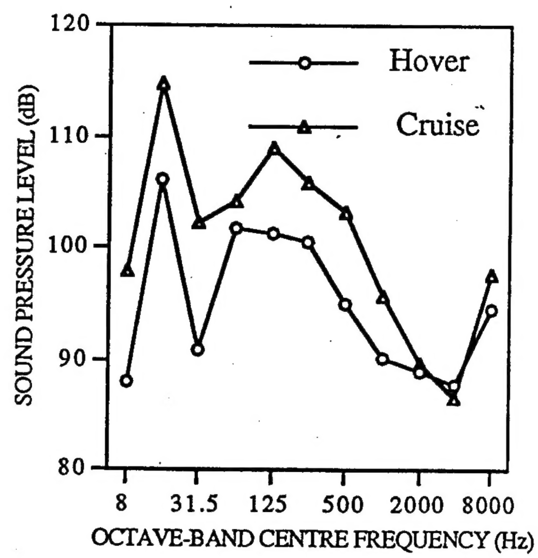

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